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# A guidance chart for most probable solution directions in sustainable energy developments

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ABSTRACT

This paper develops guidance framework for sustainable energy engineers. This guidance can be considered while looking towards some possible breakthrough solution for sustainable energy development. The research analyzes and refers core TRIZ based works related to sustainability, energy scenarios and eco-efficiency. It co-relates TRIZ philosophy, methods and tools in purview of energy and sustainability. It proposes guidelines in a tabular chart form which can help engineers as a framework in development of renewable and sustainable energy related future Progress. It provides most probable solution directions for forming the right conceptual solution before getting into detail design stages. Towards the end, it proposes a methodological flow chart for using the developed framework.


**Contents**



## 1. Introduction

Energy is an essential input for today's industrial, commercial, social and other domestic life sectors. With ever increasing problems of limited energy resources, environmental pollution and potential risks for human survival in the future, topics like sustainability and renewability are getting extreme importance in today's world [1–3]. In recent years, a lot has been discussed in research literature addressing the topics in different context. Shortage of fossil fuels, pollution and health hazards involved, wastage of energy for inefficient technologies, technical and fundamental limitations and social prospects involved in new energy developments are some major areas of such discussions [3–6]. On the other hand, main concerns are raised for the lack of current capacity of alternative energy resources, which are sought as solutions to above mentioned issues. Continuous efforts are made for technological advancement and feasible solutions formulation, which can address issues like pollution and health hazards, global warming, less production by non-conventional/alternative energy resources, energy conservation and wastage of resources etc. [3,7–13]. A lot of efforts have been made over the past for improvement of the situation and awareness of the issue. As an output of these efforts, terms like green technologies, environment friendly, environmentally benign, energy conservation, energy efficiency, eco-efficiency, sustainable energy, renewable energy etc are coined up [14–17]. Reading through the research literature, one can see that all these terms are more or

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less connected to issues mentioned above. The purpose of all these is somehow "Improving the scenario for continuous supply of energy for today and tomorrow, with least possible cost and without adding or at least minimizing harmful effects to environment". All slogans/initiatives like "Go green", "Green Grid", "climate saver computing initiative (CSCI)", energy management systems, demand side management and other efforts of reducing energy waste show the increasing concerns related to environmental sustainability issues. Energy resources whether used directly by consumer (conventional fuels in cars, machines etc.) or indirectly (e.g. Electricity produced by various conventional resources) add to the situation [7], [18–22].

In problem scenario discussed above, futuristic approach regarding energy resources conservation, generation and efficient usage is a big concern. Adding environmental/ecological concerns together with energy shortage problem adds complexity to the situation. This research recognizes the fact that meeting sustainability criteria, having complexity discussed above, is necessary for any sustainable development. The research seeks to build a directional guidance for energy workers (energy planners/engineers etc.) to seek probable/potential directions of working, while keeping in view all needed criterion of sustainability. It takes TRIZ approach and uses TRIZ patents' knowledge base for producing the aimed guidance. Initially, this research discussion summarizes the relation of sustainable energy to renewable energy and energy efficiency, while taking into account environmental concerns. It further narrates different energy and sustainability researcher's works, who took TRIZ based approach for proposing problem solutions. It links different energy scenarios and sustainability developments made by researchers, and towards the end, it summarizes a guidance framework along with a methodology chart. The produced guidance chart/framework aims to support energy workers (energy teams/engineers) at conceptual solution phase [23]. The chart can be used by energy professionals for futuristic guidance, to have a "holistic" view of renewable and sustainable energy related elements and more practical future solution directions.

## 2. Sustainable development and TRIZ

The most appropriate definitions of sustainable development, among all others are as:

> Development that meets the needs of the present without compromising the ability of future generations to meet their own needs [24,25], the ability to meet the needs of the present while contributing to the future generations' needs [26].

For getting sustainability in new development, it is a well established fact that developers must be able to incorporate sustainable development ideas at invention and design phase of development [14]. Tools and models are also needed to be developed in order to give the developers a "holistic" view of their work, and this task is very multidisciplinary [14,27,28]. Geddies [28] pointed out a few issues that are relevant to many professions including engineering, where practitioners attempt to assess the future direction of markets and economies are as follow [14]:

– To learn to forget what has always been done in the hope of discovering new insight.
– To know the differences between a fad (short life span- when it is out, it is really out of fashion) and a trend (long life span- makes basic sense and has sustaining value).
– For every trend there is a counter-trend which exists in tandem.
– Compromise does not work, least common denominator does work (because it reflects the true concerns and commitments of all the players).
– No social trends ever swing back along the same path.

Considering above mentioned issues for sustainable development, this research opted TRIZ for certain reasons. TRIZ is a systematic methodology for product design, process design and system improvement. When a solution seeker/solution designer tries to solve an innovative problem, it is usually a system incompatibility, deficiency or conflict problem. As the designer changes certain parameters of the system in his design problem, it might make other parameters bad. Traditionally, the designer makes compromise with this kind of contradicting situations and restricts himself on performing innovative design tasks [17]. The TRIZ method is an available tool for the designer to handle this conflict conditions during the innovative design problem solving process [29]. The TRIZ method was developed in the former Soviet Union by Altshuller, who had analyzed over 400,000 patents to build the contradiction table and 40 inventive principles. Keeping in view the sustainability related issues pointed out by Geddies [28], TRIZ was chosen for this research development. TRIZ offers a set of methods and tools to address all issues related to sustainable development which had been pointed out by Geddies [28]. The TRIZ tools corresponding to sustainable development factors are shown in Table 1. It addresses contradictions (Contradiction Matrix) and while keeping assessment of current status (*S*-curve) and deficiencies (Why-what, 9-windows), it foresees the future dynamics of expected development (TESE). TRIZ tools and methods help breaking psychological inertia (9-windows and patents' database linking across fields). Engineers looking for sustainable development advancements can assess desired results and impacts on all stake holders. It provides support to explore the deep insight dynamics of system or process under improvement (IFR, function analysis, 9-windows).

Comparison in Table 1 demonstrates capability of TRIZ to address sustainability related issues. Different researchers have used TRIZ application for answering issues related to sustainable energy development factors described in research literature.

**Table 1**
Sustainable development issues and related TRIZ tools.

| Sustainable development issues [28] | TRIZ tools addressing the issue |
|---|---|
| To learn to forget what has always been done in the hope of discovering new insight | Breaking psychological inertia—TRIZ tools of IFR, contradiction matrix, 9-windows, space and time interface |
| To know the differences between a fad (short life span- when it is out, it is really out of fashion) and a trend (long life span- makes basic sense and has sustaining value) | TRIZ tools of IFR, 9-windows (time and space expansion), *S*-curve, TESE |
| For every trend there is a counter-trend which exists in tandem | TRIZ tools of function analysis, Why-What analysis |
| Compromise does not work, least common denominator does work (because it reflects the true concerns and commitments of all the players) | TRIZ tools of resources and constraints (making bas as good), contradictions matrix |
| No social trends ever swing back along the same path | TRIZ tools of TESE |

## 3. Sustainable energy and future approach

Different but closely related definitions of sustainable energy are found in research literature [30–32]. In research literature, energy efficiency and renewable energy are said to be the twin pillars of sustainable energy [30]. For the purpose of this discussion, following sustainable energy definitions are taken:

> Effectively, the provision of energy such that it meets the needs of the present without compromising the ability of future generations to meet their own needs…. Sustainable Energy has two key components: renewable energy and energy efficiency [31]. and Energy which is replenish-able within a human lifetime and causes no long-term damage to the environment [32].

As per definition for sustainable energy, elements involved with renewable energy, environmental efficiency and safety (damage to environment) are analyzed by TRIZ approach. Searching through TRIZ database and methods for critical elements pertained to sustainable energy; guidance chart is compiled to provide guidance for energy workers. For this analysis, definition taken for renewable energy is as defined by International Energy Agency (IAE): "Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun or the heat generated deep within earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and bio-fuels and hydrogen derived from renewable resources [33]". Major reasons for exploring renewable resources are continuity of energy supply for future generations as well as reducing hazardous impacts on environment while using the energy. According to definition of sustainable energy, damage of environment is another major concern for sustainable energy development. Environmental efficiency is closely linked to working of sustainable and renewable energy development concerns. Terms like "Go Green", "Green technologies" and "Eco-Efficiency" are all inter-related. The term "Eco-Efficiency" is taken as a suitable and comprehensive term for this analysis. The term eco-efficiency was coined by the World Business Council for Sustainable Development (WBCSD) in its 1992 publication "Changing Course". It is based on the concept of creating more goods and services while using fewer resources and creating lesser waste and pollution [15].

With the aim of building a comprehensive guidance for engineers, environmental elements and energy elements are mapped to TRIZ database. Related inventive principles and possible future transitions are narrated in graphical and tabular forms.

### 3.1. TRIZ and eco-efficiency principles

WBCSD has pointed out seven major elements in considering eco-efficiency of developing environmental friendly products or processes for reducing environmental impacts [34].

A. Reduce the material intensity of its goods and services.
B. Reduce the energy intensity of its goods and services.
C. Reduce the dispersion of any toxic materials.
D. Enhance the recyclability of its materials.
E. Maximize the sustainable use of renewable resources.
F. Extend the durability of its products.
G. Increase the service intensity of its goods and services.

As each element improves or more elements improve simultaneously, it will produce high eco-efficiency products or services. Taking into account the major elements to be considered for eco-efficient development, Chih-Chen et al. [17] worked towards building a method for eco-efficient development using TRIZ database, methods and toolset.

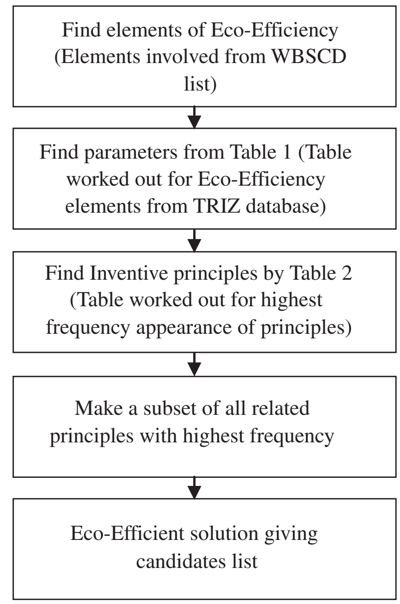


**Fig. 1.** Flowchart of green innovation design method [17].

At first, Chih-Chen et al. [17] built a relationship between eco-efficiency elements and TRIZ engineering parameters. Furthermore, they built a list of most probable TRIZ inventive principles (based on frequency of appearance) to address any specific engineering parameters linked to an eco-efficiency element under consideration. Following this approach they devised a methodology flowchart (Fig. 1) to sort out the possible development options which fulfill the requirement of eco-efficiency criterion.

Based on Chin-Chen et al. work, Morgan [16] further worked on the environmental analysis in terms of TRIZ database. The research concentrated more on inventive principles with higher frequency of appearance, considering those as most probable improvement giving principles for environmental developments. The work defined and analyzed TRIZ engineering parameters (Environmental Engineering Characteristics (EECs) as in [16]), which are more closely related to environmental issues. It further devised a list of the most probable TRIZ inventive principles to be considered for environmental improvements based on frequency of appearance (Fig. 2).

According to frequency graph shown in Fig. 2, Table 2 shows top 5 inventive principles. Inventive principles that have been sought are considered as most probable principles linked to eco-efficient and environmentally safe development for this research. The principles database can further be expanded for examining more inventive candidates by including lesser frequent principles as well.

### 3.2. TRIZ and energy principles

Morgan derived an energy matrix shortlisted from TRIZ Contradiction Matrix. The research [16] related specific parameters explicitly related to energy contradictions. Taking approach of highest frequency appearance as the most probable inventive principles to be considered, the research built a list of TRIZ inventive principles as Energy contradiction resolving principles (Fig. 3).

From frequency graph shown in Fig. 3, Table 3 shows top 5 inventive principles. Inventive principles sought are considered

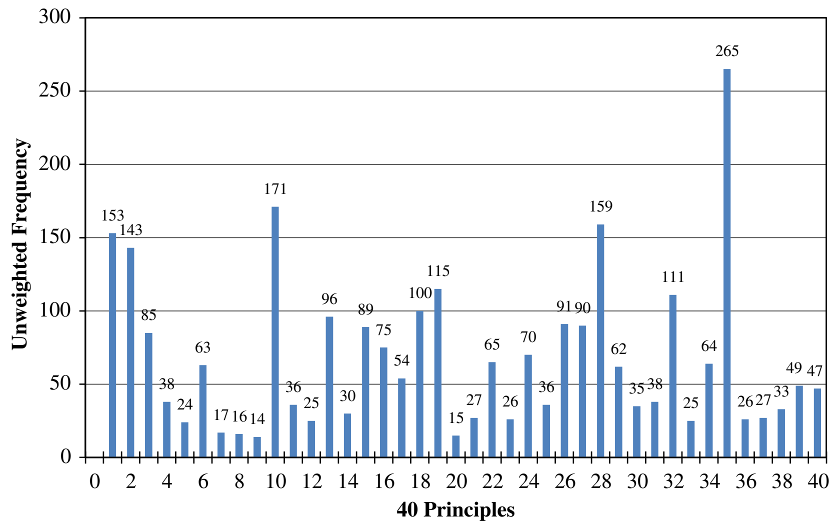


**Fig. 2.** Frequency of TRIZ 40 principles with respect to the environmental engineering characteristic contradictions [16].

**Table 2**
Five principles that appear with the highest frequency [16].

| Most frequently appearing principles for environmental engineering characteristics | | | |
|---|---|---|---|
| Rank frequency | | Principle of no. | Principle |
| 1 | 265 | 35 | Transformation of properties |
| 2 | 171 | 10 | Prior action |
| 3 | 159 | 28 | Replacement of mechanical system |
| 4 | 153 | 1 | Segmentation |
| 5 | *143* | 2 | Extraction |

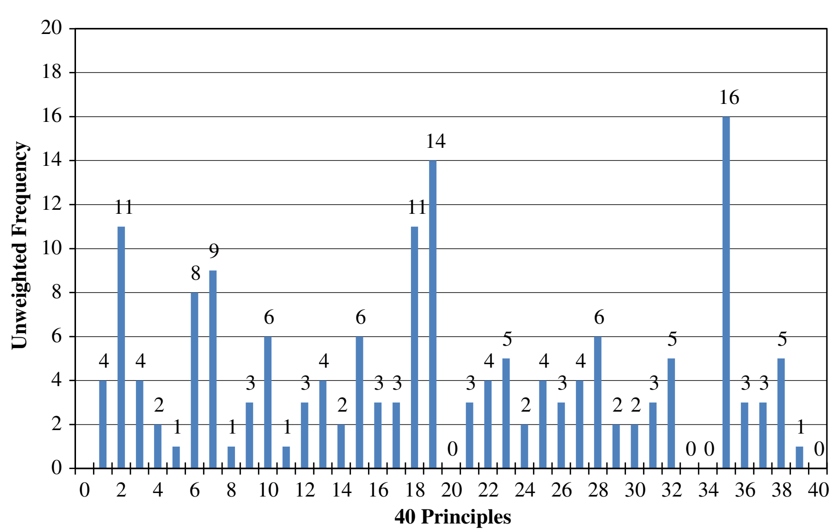


**Fig. 3.** Frequency of TRIZ 40 principles with respect to the energy saving characteristic 19, 20 and 22 [16].

as most probable principles linked to energy related development for this research. The principles database can further be expanded for trying more inventive candidates by including less frequent principles as well.

By combining the two highest frequency findings (Tables 2 and 3), Environmental and Energy related most probable Inventive principles are derived as reference for this research (Table 4).

Summarized TRIZ inventive principles (in Table 4) are considered as the most probable candidates for generating improvement in sustainable energy related developments. The list can further be expanded by considering lower frequency principles as well, but

**Table 3**
Five principles that appear with the highest frequency [16].

| Most frequently appearing principles for energy engineering characteristics | | | |
|---|---|---|---|
| Rank | Frequency | Principle of no. | Principle |
| 1 | 16 | 35 | Transformation of properties |
| 2 | 14 | 19 | Periodic action |
| 3 | 11 | 2 | Extraction |
| 4 | 11 | 18 | Mechanical vibration |
| 5 | 9 | 7 | Nested doll |

**Table 4**
The principles that appear with the highest frequency as Environmental and Energy characteristics improving candidates.

| Environment-energy inventive principles | |
|---|---|
| TRIZ inventive principle of no. | Principle |
| 35 | Transformation of properties |
| 19 | Periodic action |
| 2 | Extraction |
| 18 | Mechanical vibration |
| 7 | Nested doll |
| 10 | Prior action/preliminary action |
| 1 | Segmentation |
| 28 | Replacement of mechanical system |

for depicting the results of this research, we limit it to the list in Table 4.

### 3.3. TRIZ and future energy scenarios

Considering today's energy crisis in the world and the need for a futuristic approach for energy endurance, Bhushan et al. [35] discussed different possible energy scenarios for the future. According to worked out possible future scenarios, their work shows sustainable and renewable energy involvement as the key for future survival strategies. The research suggested possible future energy developments and strategies in relation with TRIZ laws of system evolution. Following TRIZ concept that “technical

**Table 5**
Future strategic directions for Energy developments and TRIZ trends of evolution [35–38].

| TRIZ main laws of evolution | TRIZ sub-trends | Energy-strategies |
|---|---|---|
| • Non-uniform evolution of sub-systems<br>• Harmonization of rhythms<br>• Shortening of energy flow path | 1. Sub-system trimming<br>2. Operations trimming<br>3. Low value component trimming<br>4. Reducing energy conversions<br>5. Boundary breakdown<br>6. Damping<br>7. Senses interaction<br>8. Feedback/feed-forward control<br>9. Action coordination<br>10. Rhythm coordination<br>11. Nesting (time and interface)<br>12. Design methodology (adv coordination plan)<br>13. Level of control<br>14. No. of states of control | Energy nets: With the advent of bio-fuels, food and fuel supply chains are integrated. The resulting supply chain efficiencies salvage the escalating global standoff between food corps and fuel corps. Vegetable oils are used both for food and fuel. All households has simple oil converters |
| • Transition to higher level system<br>• Law of system completeness | 1. Heterogeneity of integration<br>2. Degree of integration depth<br>3. Variety of integrated systems<br>4. Mono-Bi-Poly (interface)<br>5. Boundary breakdown (space)<br>6. Reducing energy conversions<br>7. Level of self containment<br>8. Degree of freedom<br>9. Use of senses<br>10. Design methodology<br>11. Design point<br>12. Coordination within and with super-system | Live energy: Higher level energy systems are able to work with higher entropy energy forms e.g. movement from fossil-fuels to bio-fuels and then geothermal, wind, solar, tidal energy. Systems are also able to store and re-utilize energy wastage during transmission and use. Collaborative science and technology helps multiple domains like material science, nanotechnology, biotechnology etc. to come together and create the next level of biological energy systems the actively generate and store energy. Roads are designed with structured bumps—car suspension systems are able to store and re-use the energy generated. Bio-batteries like sugar molecules store energy captured from sunlight similar to photosynthesis in plants |
| • Increasing dynamism<br>• Harmonization of rhythms<br>• Shortening of energy flow path | 1. Substance dynamization<br>2. Field dynamization<br>3. Composition dynamization<br>4. Function dynamization<br>5. Mono-Bi-Poly (time +interface)<br>6. Process thinking/design point<br>7. Macro to Nano scale<br>8. Smart materials<br>9. Damping<br>10. Senses interaction<br>11. Feedback/feed-forward control<br>12. Action coordination<br>13. Rhythm coordination<br>14. Nesting (time and interface)<br>15. Design methodology (adv coordination plan)<br>16. Level of control<br>17. No. of states of control | Multi-energy: Systems are built for highly efficient utilization of popular energy sources e.g. cars engines are able to operate on petrol, diesel, natural gas, CNG, LPG, Ethanol or any combinations.Systems are able to dynamically adapt to a larger variety of energy sources, albeit with only above average efficiencies, initially. All cars come pre-equipped with variety of energy crunchers—solar panels, batteries, diesel engines, wind sails etc |

**Table 5** (*continued*)

| TRIZ main laws of evolution | TRIZ sub-trends | Energy-strategies |
|---|---|---|
| • Transition to micro-level | 1. Senses interaction<br>2. Action coordination<br>3. Rhythm coordination<br>4. Nesting (time and interface)<br>5. Design methodology (adv coordination plan)<br>6. Level of control<br>7. No. of states of control<br>8. Smart materials | Drop energy: Energy consumption is measured in milliliters or equivalent rather in liters or equivalent. Oil supply and demand measured in liters rather than barrels |
| • Increasing dynamism<br>• Increasing controllability | 1. Senses interaction<br>2. Feedback/feed-forward control<br>3. Nesting (time and interface)<br>4. Design methodology (adv coordination/control plan)<br>5. Level of control<br>6. No. of states of control<br>7. Substance dynamization<br>8. field dynamization<br>9. Composition dynamization<br>10. Function dynamization<br>11. Mono-Bi-Poly (time +interface)<br>12. Process thinking/design point<br>13. Macro to Nano scale<br>14. Smart materials | Modular energy: Systems become increasingly segmented and modular. Standardization helps iron out inefficiencies in energy storage, transmission and use. New plug and play automobiles are widely used. Users can assemble their own cycles, motorbikes and cars, or convert one to another with easy toolkits |

systems do not evolve randomly, they follow certain laws of system evolution", their work emphasizes the capability of TRIZ to guide for the future developments in energy sector [35]. Using basic work from Bhushan et al., this research deepens the suggested relation with TRIZ major trends group by further breakup into sub-trends for more detailed measures. Major trends were divided into sub-trends, derived from TRIZ researchers' work [36–38]. This major trends division into sub-trends in relation with energy strategies by Bhushan et al., is detailed as in Table 5.

The research [35] further presents a flowchart of "Ideal Final Result (IFR)" for future energy scenario (Fig. 4). Depicting an ideal result as to achieve or move towards most ideal sustainable energy for future developments. The flowchart depicts current scenarios (fossile-fuels, bio-fuels etc) and if followed backward (sustainable energy developments), it reaches ideality (self sustaining, self cleaning energy). It is also a TRIZ concept and base of TRIZ-IFR tool. It proposes to focus ideal results, and work for getting closer to ideality while following back to ideal situations from current scenario [37].

### 3.4. Guidance for sustainable energy development

A summarized framework derived from TRIZ based guidance for energy workers has been compiled as in Table 6. TRIZ based innovative guidance is derived from the above discussed TRIZ database inference for sustainable development, energy and environment. The engineers may look for innovative ideas and potential directions to sort out problems from this framework.

To help seeking guidance from TRIZ, using detailed TRIZ database and the inferred results, a methodology chart has been devised (Fig. 5). The guidance methodology will give a "holistic" view to engineers regarding directions and requirements for sustainable energy development in future. Directing them to a feasible conceptual solution step by step, led to a sustainable and eco-efficient development. The conceptual solution may further be evaluated and implemented through solution design steps by engineers.

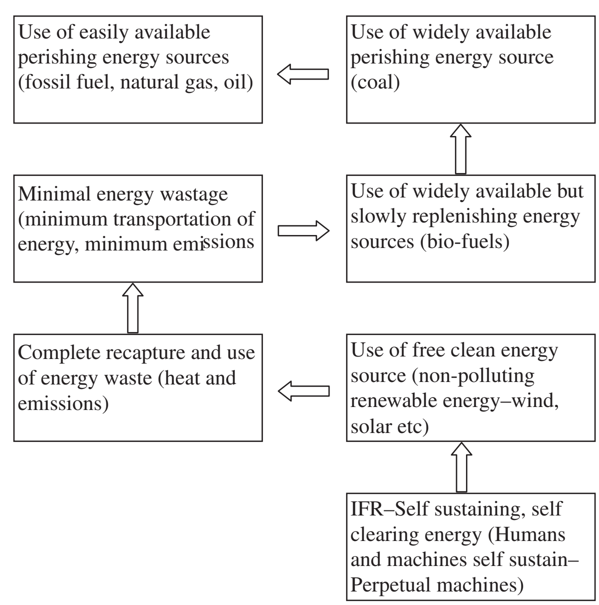


**Fig. 4.** Probable IFR chart for energy scenario [35].

## 4. Conclusions

TRIZ methods and toolset have strong capability for addressing problems related to sustainable energy developments. Researchers have analyzed and built TRIZ relation with sustainability, energy and eco-efficiency. Co-relating and cross referencing these researches, which were worked out separately for sustainable developments, environment and energy can produce a holistic TRIZ guidance for

**Table 6**
Directions for energy workers for most probable sustainable energy related development (Tables 4 and 5).

| TRIZ trends derived for future energy related development | Environment-energy inventive principles | Energy strategies | Energy development current standing |
|---|---|---|---|
| 1. Sub-system trimming | Transformation of properties | Energy nets development strategy | TRIZ S-curve (Life cycle analysis) |
| 2. Operations trimming | Periodic action | Live energy development strategy | TRIZ TESE (sub trends transitions standing) |
| 3. Low value component trimming | Extraction | Multi-energy development strategy | TRIZ IFR Ideality (consideration of benefit Vs. cost-Harm) |
| 4. Reducing energy conversions | Mechanical vibration | Drop energy development strategy | TRIZ 9-windows (time and space expansion to foresee need in future) |
| 5. Boundary breakdown | Nested doll | Modular energy development strategy | |
| 6. Nesting (time+interface) | Prior action/preliminary action | | |
| 7. Damping | Segmentation | | |
| 8. Senses interaction | Replacement of mechanical system | | |
| 9. Feedback/feed-forward control | | | |
| 10. Action coordination | | | |
| 11. Rhythm coordination | | | |
| 12. Design methodology (adv coordination plan) | | | |
| 13. Level of control | | | |
| 14. No. of states of control | | | |
| 15. Heterogeneity of integration | | | |
| 16. Degree of integration depth | | | |
| 17. Variety of integrated systems | | | |
| 18. Level of self containment | | | |
| 19. Degree of freedom | | | |
| 20. Substance dynamization | | | |
| 21. field dynamization | | | |
| 22. Composition dynamization | | | |
| 23. Function dynamization | | | |
| 24. Mono-Bi-Poly (time+interface) | | | |
| 25. Process thinking/design point | | | |
| 26. Macro to Nano scale | | | |
| 27. Smart materials | | | |

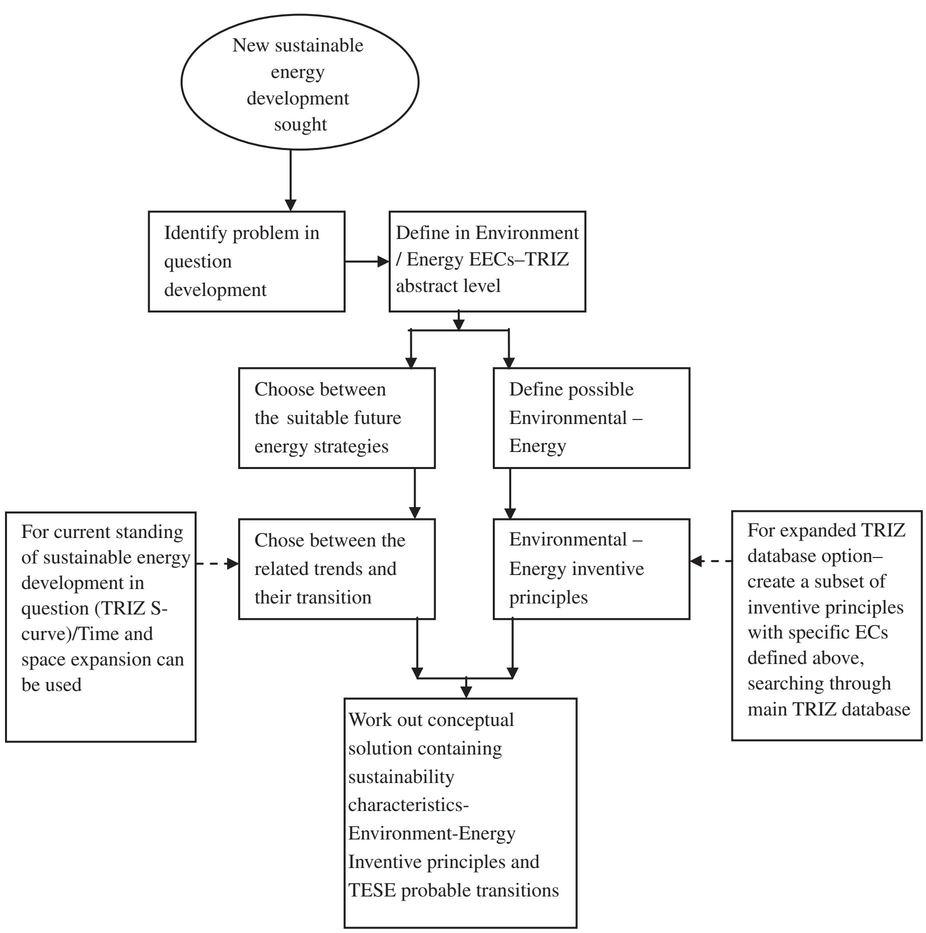


**Fig. 5.** Methodology chart for seeking sustainable energy development related solution.

engineers. Building on the previous researchers' work, this research is able to suggest a summarized guidance framework. By adding further details from different TRIZ researchers (detailed list of sub-trends) on sustainability and eco-efficiency development factors sorted before, the chart provides a holistic view of all elements to be considered for sustainable energy related developments. In addition, the research provides a stepwise methodology for working through the guidance framework. The guidance framework may support engineers to strengthen and widen their possibility of innovative works more effectively.

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